Three-Dimensional Modeling of Optical Turbulence

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Objective

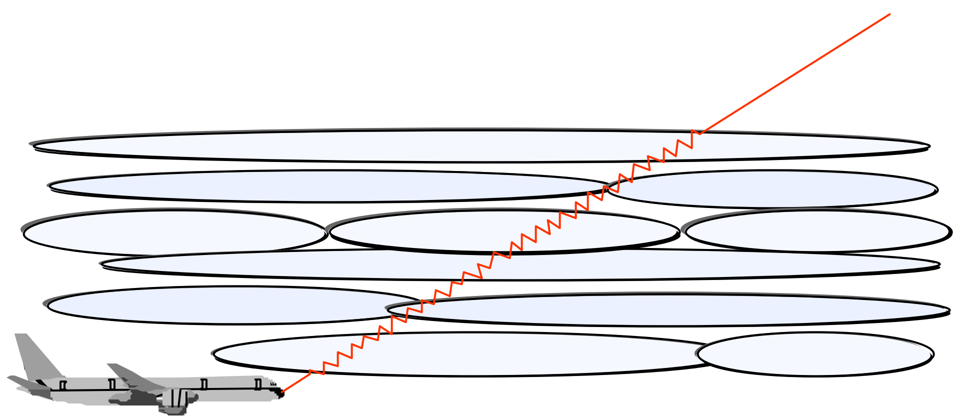
- To produce 3-D optical turbulence forecasts for
  - Theater domains
  - Operational use

Outline of Presentation

- Background of weather impacts on optical turbulence
- Two-tiered modeling approach
  - Mesoscale weather forecast model
  - Optical turbulence model
- Application of the model for SAT-99
- Preliminary evaluation results
- Future Work

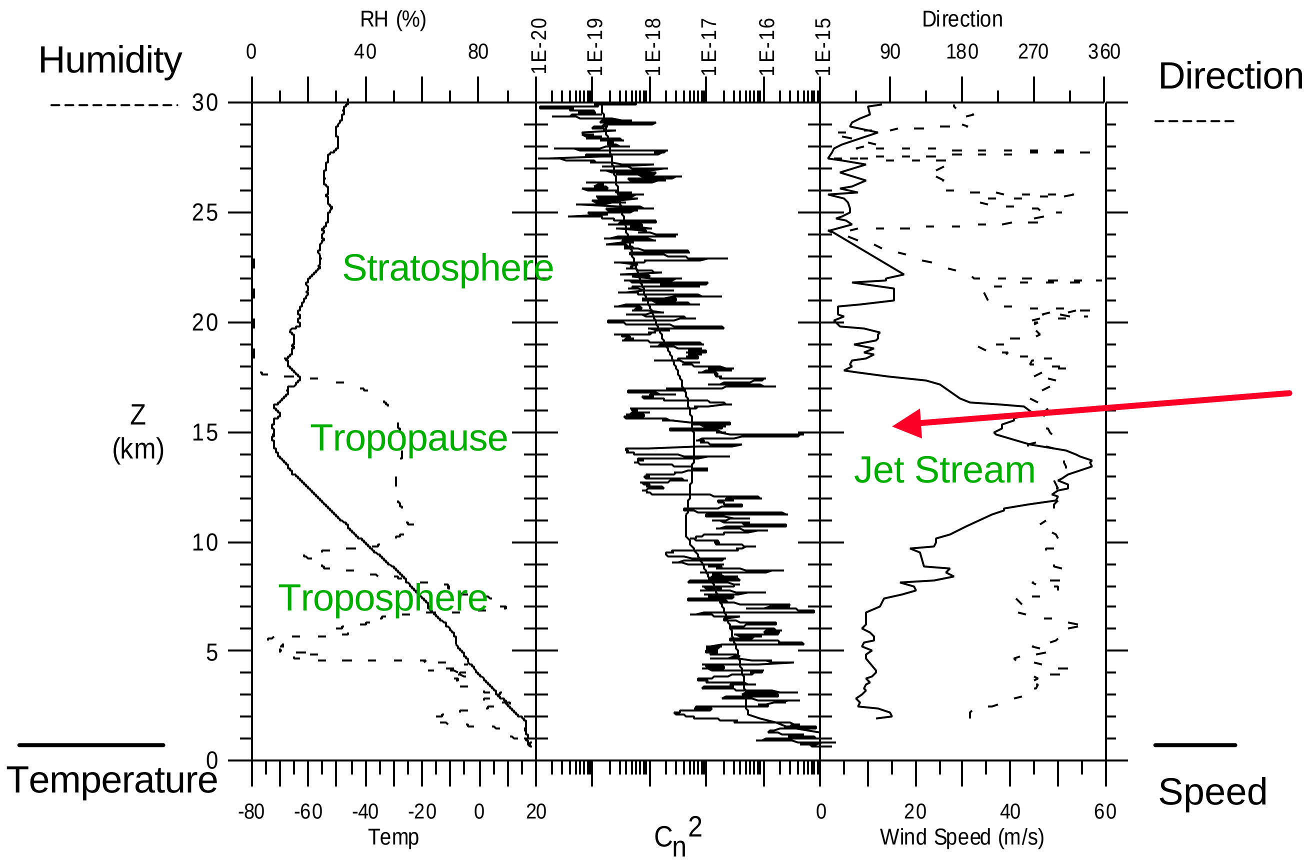
Optical Turbulence

- Phenomenon which makes stars “twinkle”
- Turbulent fluctuations occur in thin horizontal layers in the free atmosphere
  - Caused by turbulent mixing
    - Creates small-scale temperature and refractive index inhomogeneities on scales of few cm to100m
  - Acts like small lenses which tilt and defocus the laser beam as it is dwelling on the target



Atmospheric Turbulence Structure

C_n^2 varies with atmospheric conditions by orders of magnitude

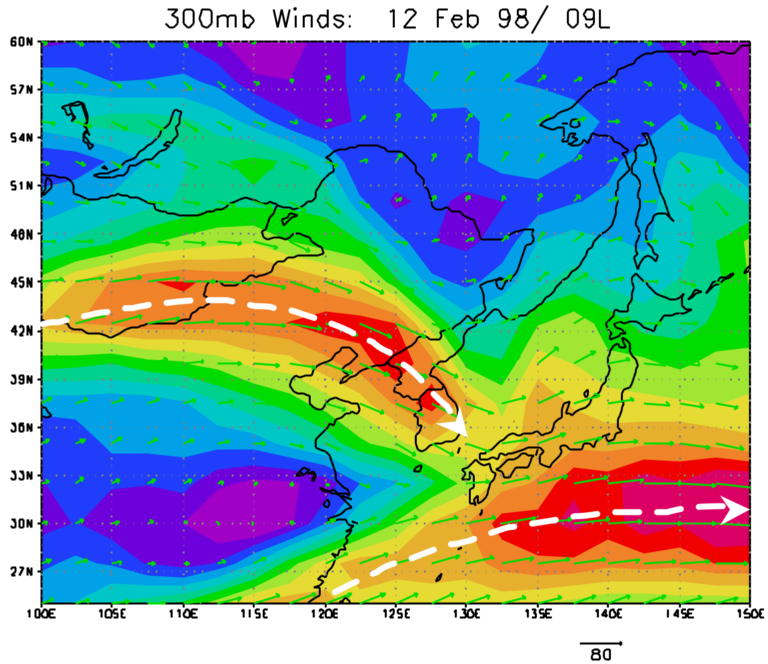


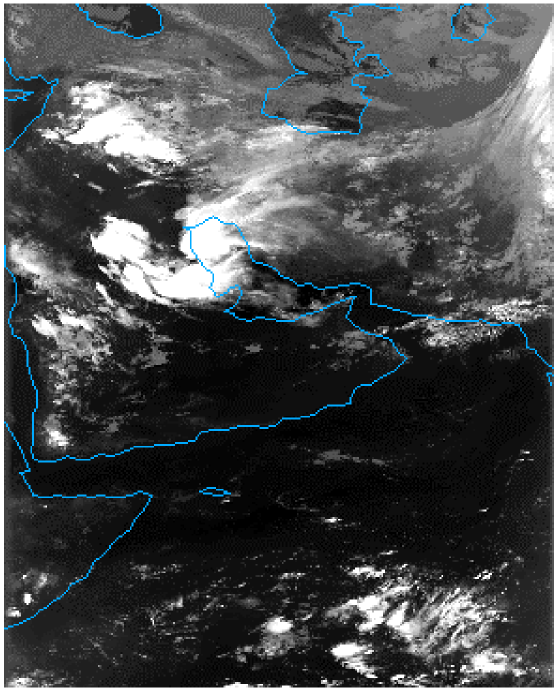
Index of Refraction Structure Constant

- **Turbulence occurs in thin layers or pancakes**
- **This layer is associated with the tropopause and jet stream**
- **Much stronger turbulence than our Clear 1 model (smooth curve)**

Weather Features Linked to Optical Turbulence

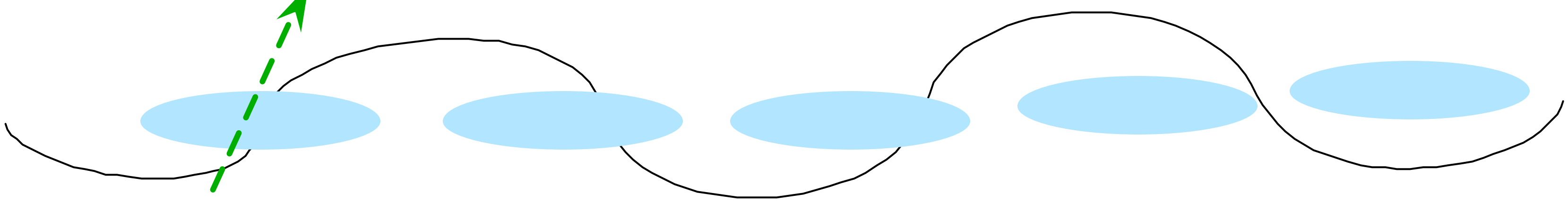
- Generated by (meteorological) "gravity wave" sources:
  - Jet streams, thunderstorms, mountain waves, and possibly land/sea temperature contrasts
- Influenced by the tropopause and atmospheric stability



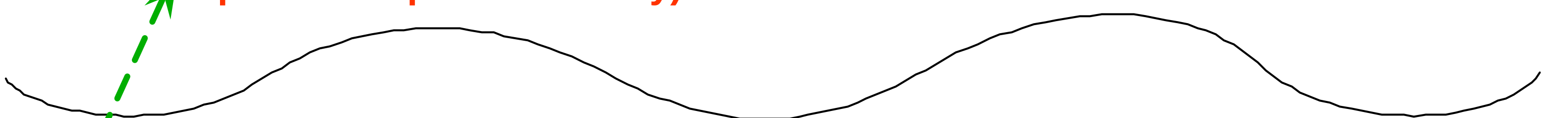


How Optical Turbulence is Generated in the Atmosphere

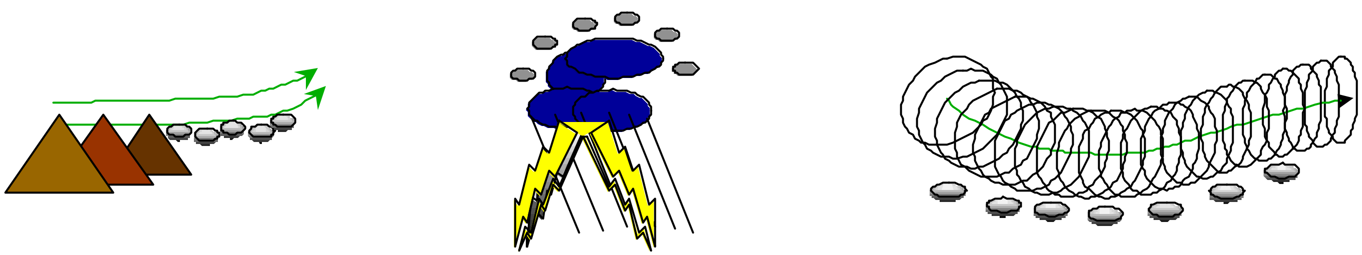
4. Finally, waves break (at the tropopause) into regions of turbulence.



3. Waves are amplified as they work their way up through the atmosphere (dependent upon atmospheric stability).



2. In addition, waves are generated over the mountains, jet streams, thunderstorms, etc.



1. Some turbulence forms around mountains, thunderstorms, and jet streams due to flow instabilities (the source regions).

Optical Turbulence Data Collection

AFRL/DEBA Aerothermal Probes

AFRL/DEBA Aerothermal Probes and Star Scintillometer

AFRL/VSBL Thermosondes

Two-tiered Modeling Approach

- Mesoscale weather forecast model
  - produces 3-D mean fields of wind, temperature, and moisture
  - resolution of 4-100 km in horizontal and 300-1500 m in vertical (free atmosphere)
- Optical turbulence parameterization model
  - uses output from mesoscale weather forecast model as input
  - produces forecast values of C_n^2

Mesoscale Weather Forecast Model

- National Center for Atmospheric Research/Penn State University Mesoscale Model Version 5 (MM5)
- Fully compressible
- Main prognostic variables
  – horizontal and vertical momentum, temperature, and pressure
- Moisture prognostic variables
  – water vapor, cloud liquid water, ice, rain, and snow

MM5

- Parameterized convection
- Vertical diffusion
  - Stable/neutral conditions: based on eddy diffusivity
  - Free convection: non-local mixing within boundary layer
- Boundary Conditions
  - upper boundary: radiative (energy passed through unreflected)
  - surface: momentum = 0; temperature computed by surface energy budget
- Model Coordinates
  - vertical: terrain following
  - horizontal: staggered

MM5

- Current mesoscale operational model at Air Force Weather Agency
  – Runs with 45 vertical levels (plans to go as high as 100)
  – Horizontal grid resolution: as low as 4 km currently
  – Horizontal boundary conditions supplied by NOGAPS forecasts
  – Optimized for multiprocessing for shared memory and distributed memory systems

Optical Turbulence Model

- Equation for optical turbulence:

$$C_n^2 = 2.8 M^2 L^{4/3}$$

$$M^2 = \left[\left(\frac{79 * 10^{-6} P}{T^2} \right) \frac{\partial q}{\partial z} \right]^2$$

- Dewan et al. (1993) statistically related measured 300m vertical wind shear with outer length scales (L)

Dewan et al. (1993) Optical Turbulence Model

- Advantages
  - Easy to adapt as MM5 postprocessor
  - Looks at pertinent parameters
- Disadvantages
  - Developed only on New Mexico data

1999 Scintilometer Atmospheric Test (SAT)

- Occurred in May-June 1999 in New Mexico region
- Purpose to test Scintillometer installed on Argus research aircraft
- Coincident thermosonde measurements made

Real-time support for SAT

- Run MM5/Dewan optical turbulence forecasting system
- Objectives
  – Assist mission preplanning process
  – Exercise the model extensively

Real-time support for SAT

- Goal
  - have C_n^2 forecasts for experiment domain in time for pre-mission weather briefing 06 UTC (00 MDT)
- Two model runs per mission
  - Initialize MM5 with 12 UTC (06 MDT) data and integrate 24 hrs
  - Initialize MM5 with 00 UTC (18 MDT) data and integrate 12 hrs

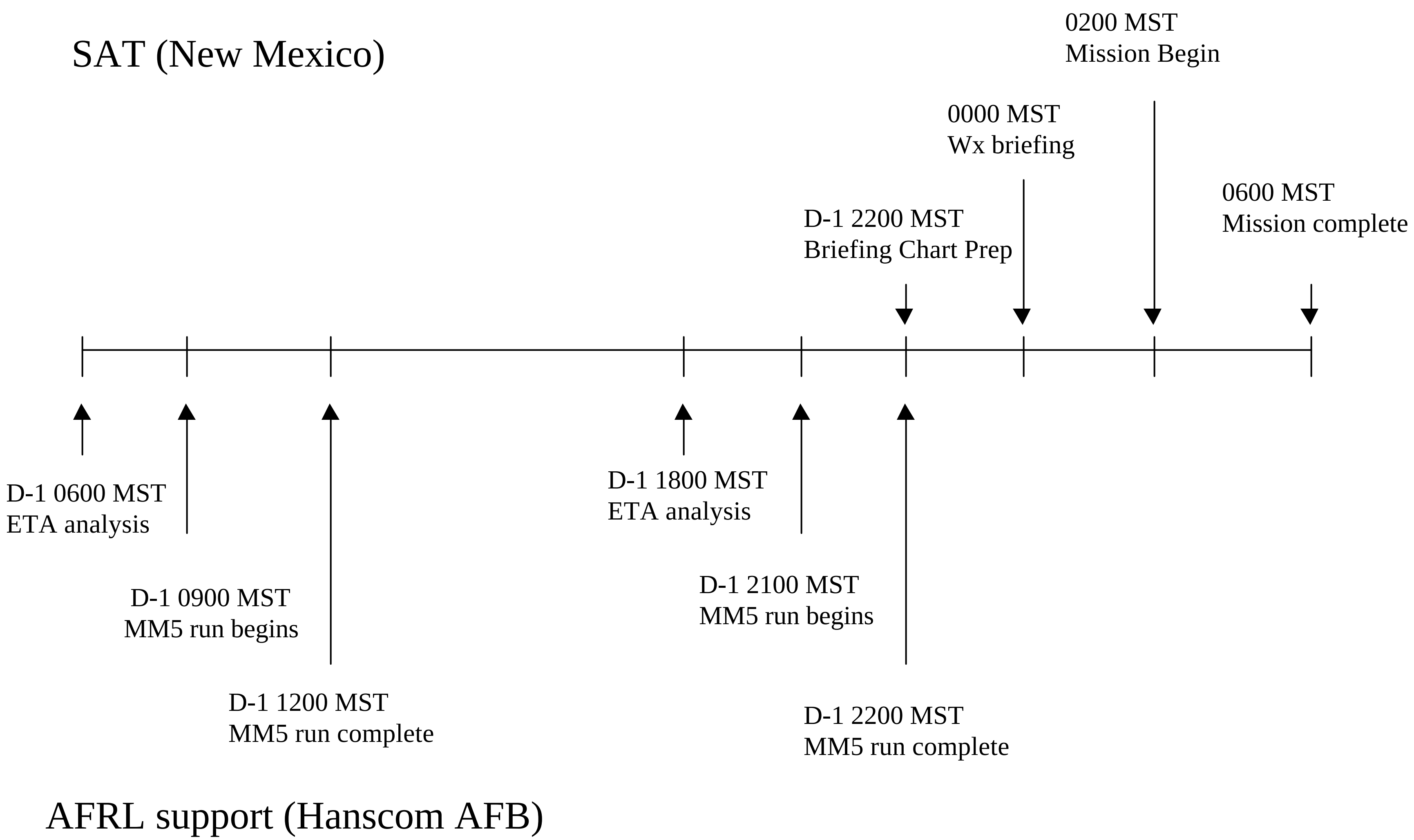
Real-time support for SAT

- Initial data and horizontal boundary conditions acquired via anonymous ftp from National Center for Environmental Prediction's operational Eta model
- MM5 and Dewan models executed on the NAVO C-90
  - queue limits reduce the resolution of the model
  - System executed between 1-3 hr of wall-clock time

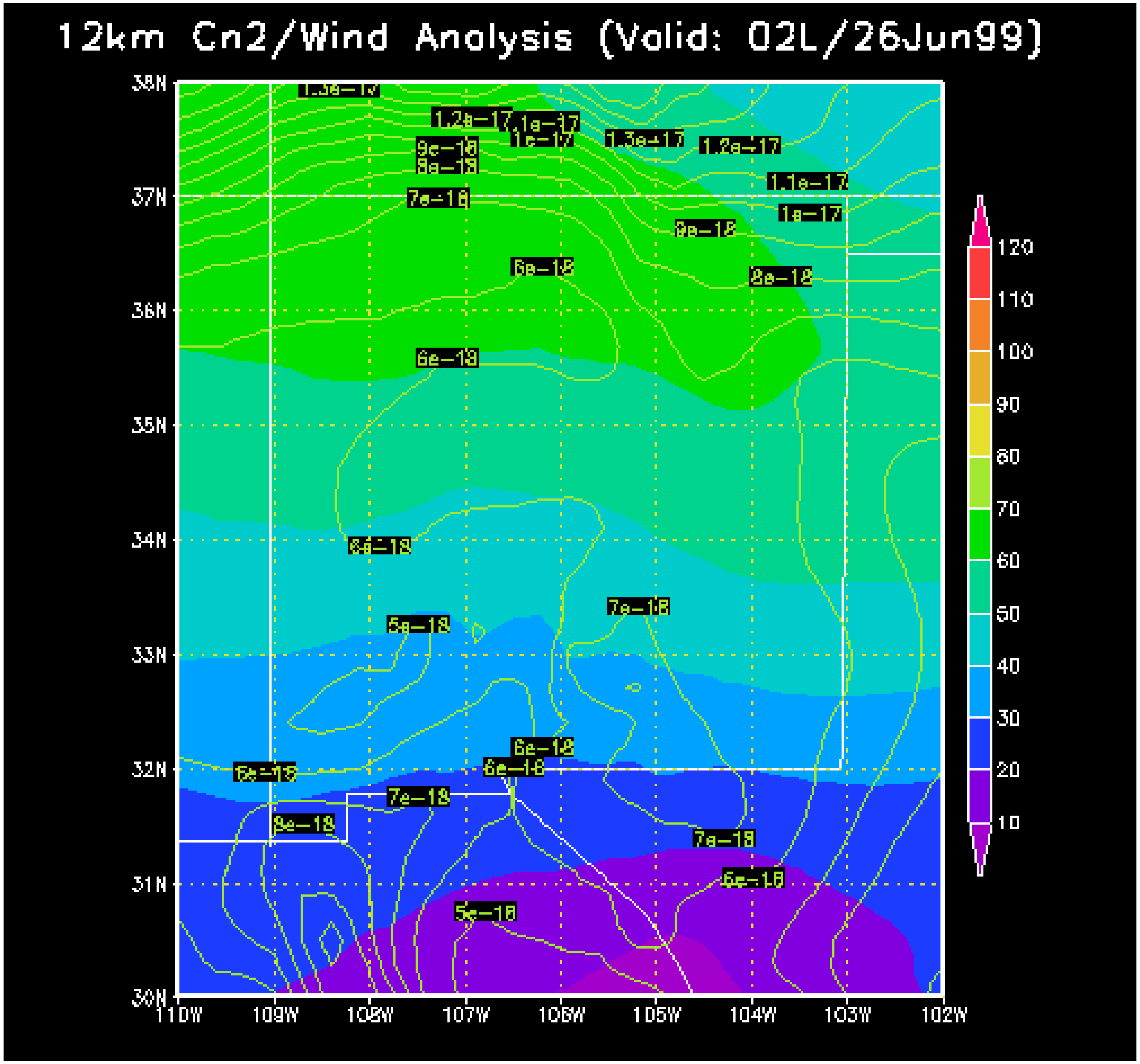
Real-time support for SAT

- MM5 mean fields and C_n^2 values converted to GrADS format and ftped to file server in New Mexico
- Weather briefer had GrADS scripts available to easily display the data

Real-time support for SAT



Optical Turbulence Forecast



Real-time support for SAT

- Results
  - Successfully provided C_n^2 forecasts to AFRL/DE Staff Meteorologist for 13 pre-mission briefings
  - Extensive exercise of MM5/Dewan forecast system led to adjustments to increase robustness and sensitivity
  - Staff Meteorologist also included MM5 wind forecasts in his briefings
  - Flexibility of output was advantageous
  - First “operational” C_n^2 forecasts produced

MM5/Dewan Optical Turbulence Forecasting System

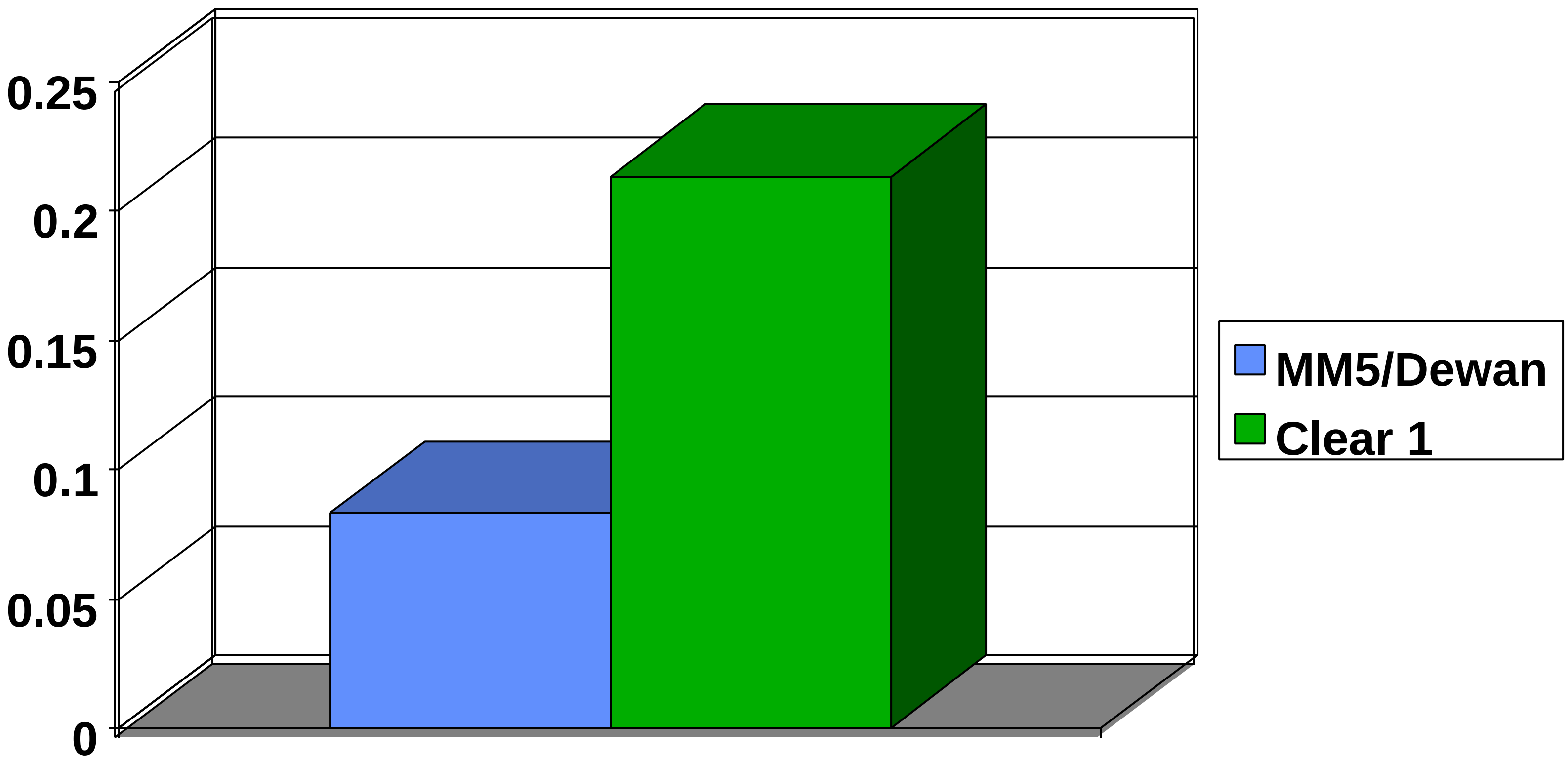
- Initial testing
  - Identification of NWP transition issues
  - Evaluation of grid point resolution on results
  - Provide baseline and develop tools for evaluation of other optical turbulence forecast techniques

Initial Tests

- Run for New Mexico cases
  – 44 vertical levels
  – 4 km horizontal resolution
- Validated against thermosonde profiles
- Compared with Clear1 model
- Results for $5000<z<18000$ m

Initial Results

RMS for Log C_n^2 along integrated balloon trajectories vs thermosonde observations



Summary

- MM5/Dewan optical turbulence forecast system has shown
  - it can be run in an operational environment
  - improved forecasts over previous benchmark (Clear 1)

Future Work

- Complete study of MM5 resolution sensitivity on optical turbulence forecasts
- Compare MM5/Dewan results with those of Walters and Miller (1999)
- Assist developers of next generation of optical turbulence models

Air Force Research Laboratory